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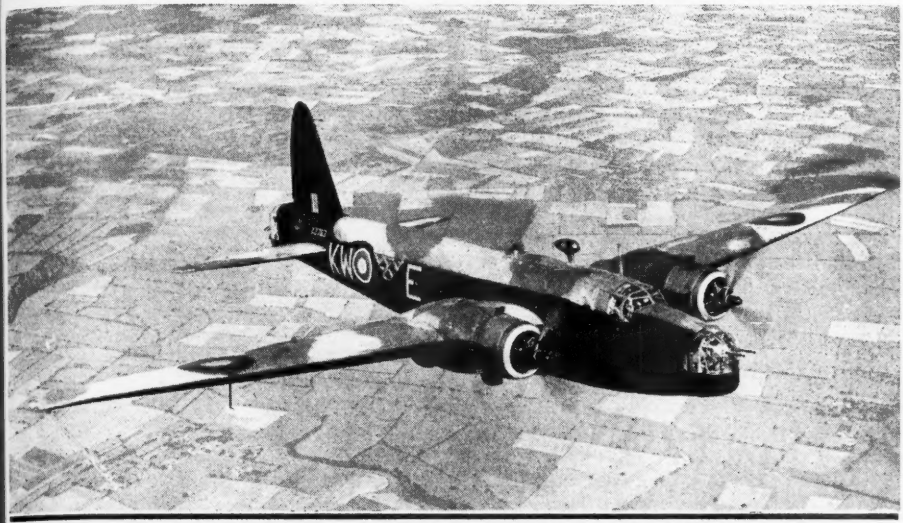
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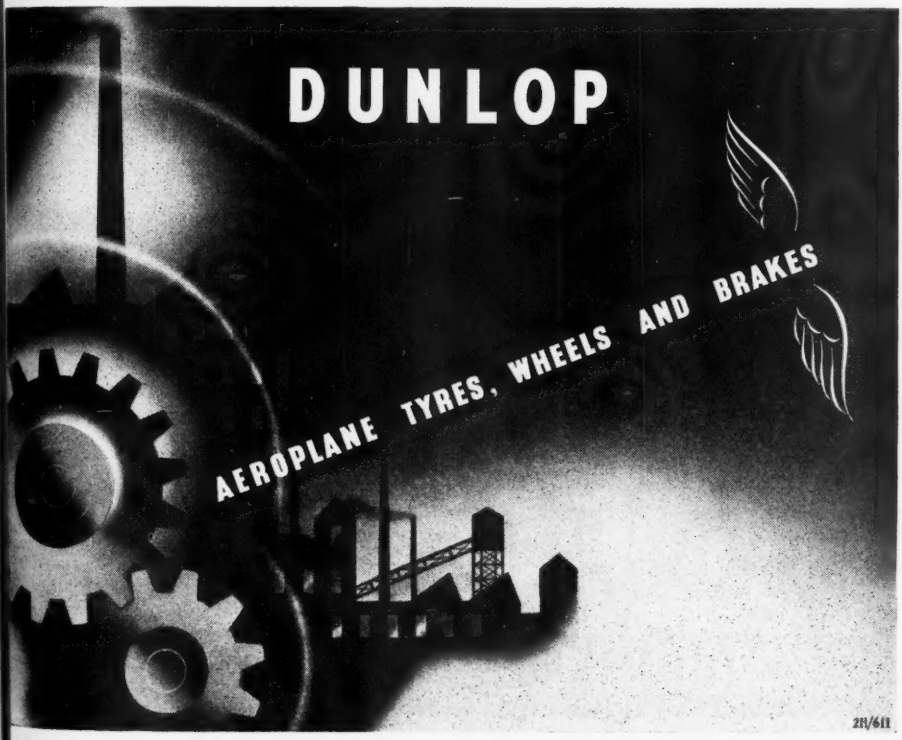
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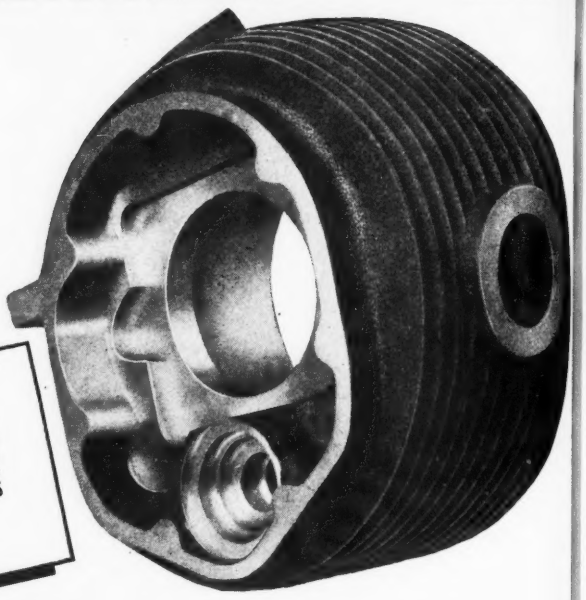

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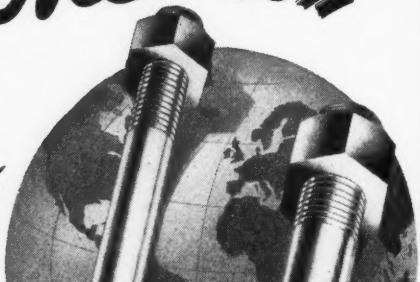

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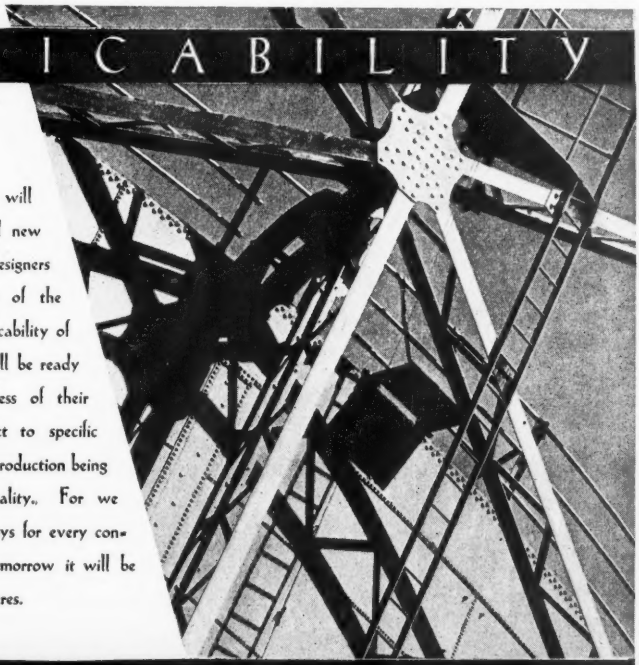

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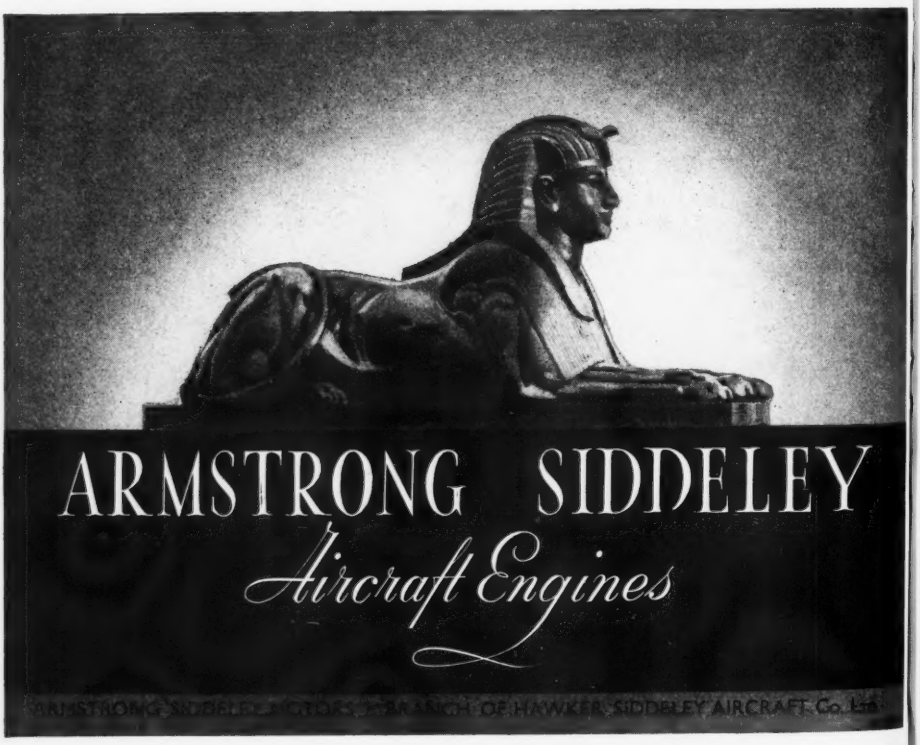

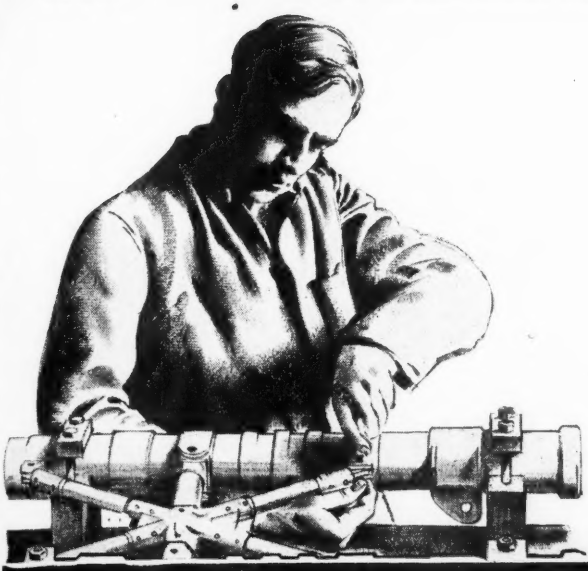

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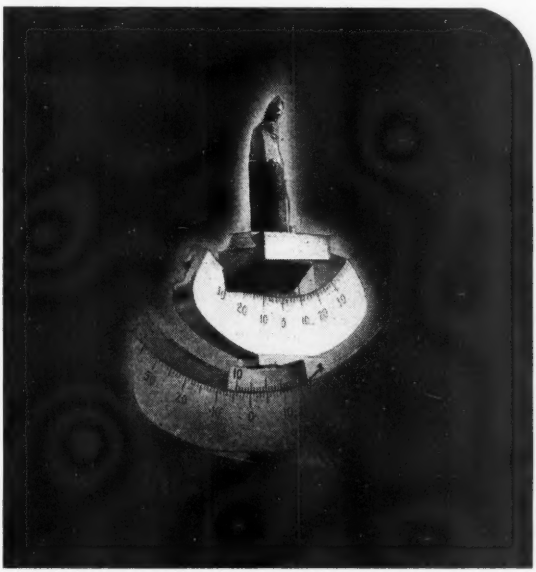

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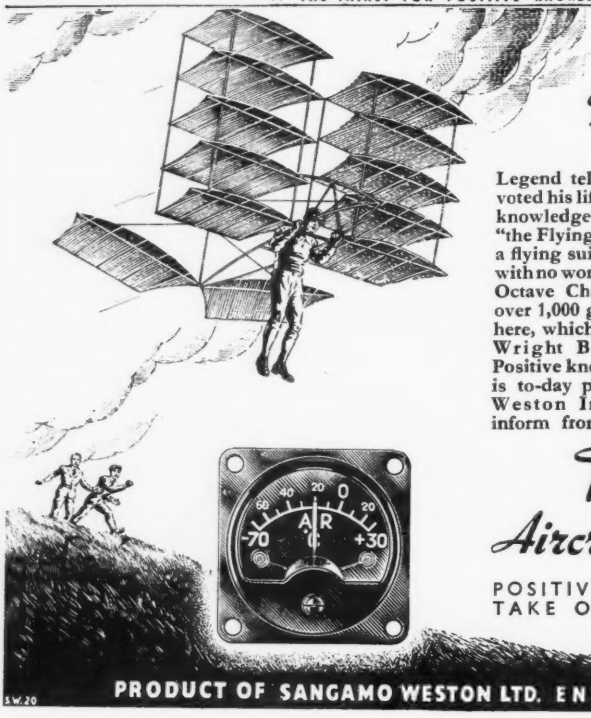

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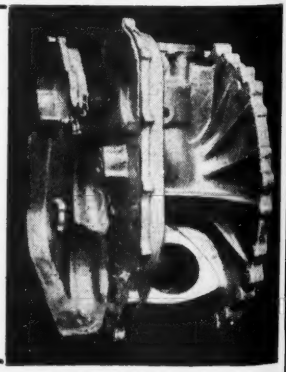

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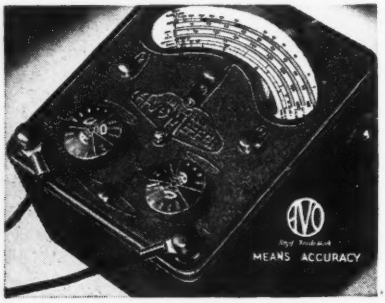

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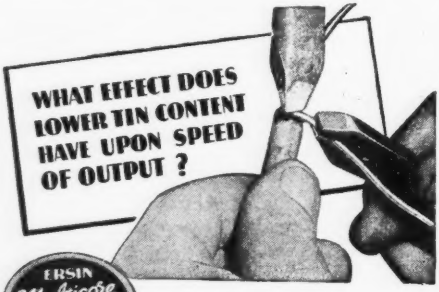

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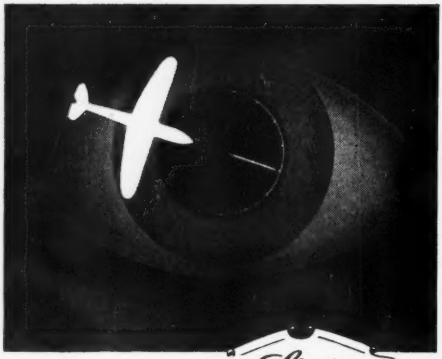

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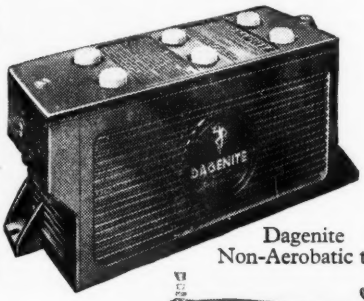

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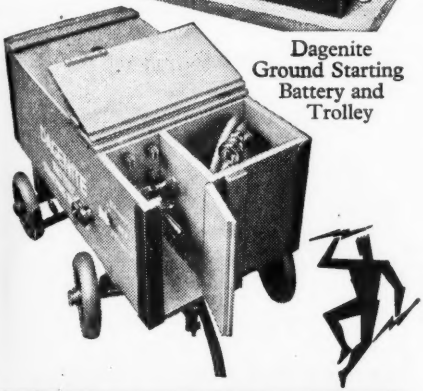

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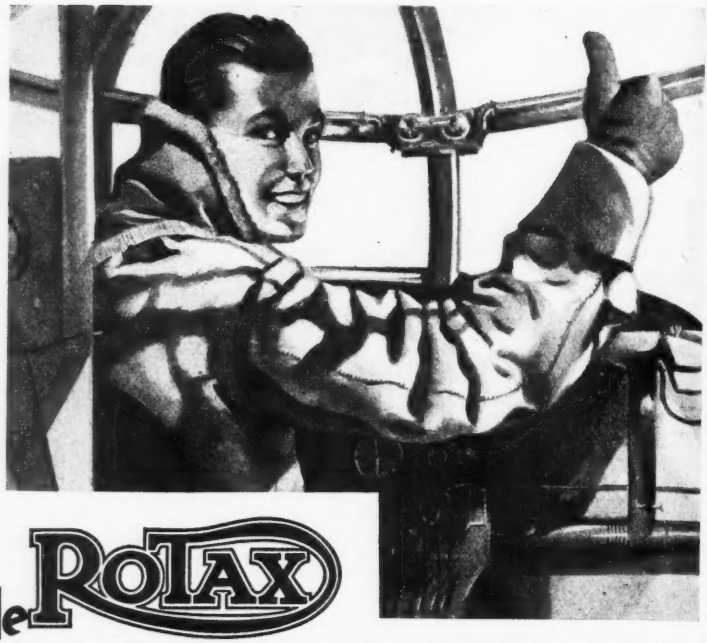

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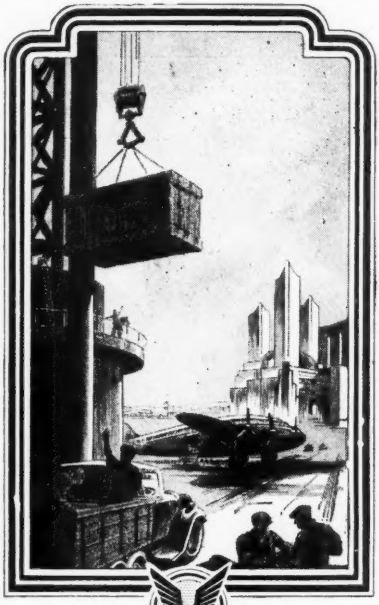

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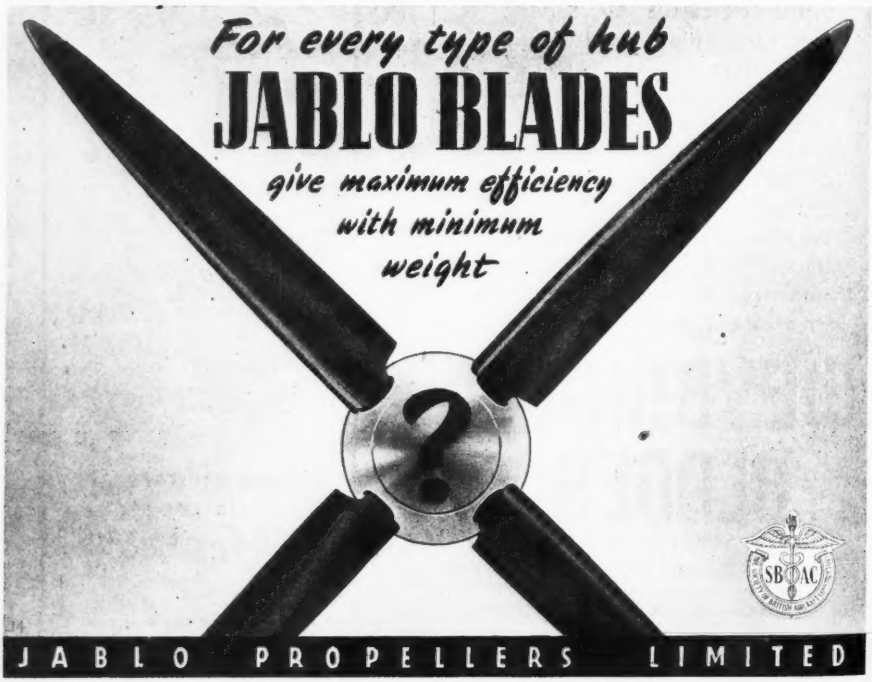

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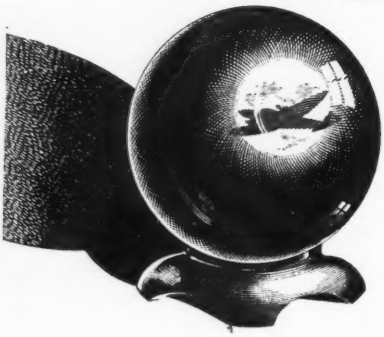

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MARCH, 1943.

Annual General Meeting.

Notice is hereby given that the Annual General Meeting of the Royal Aeronautical Society, with which is incorporated the Institution of Aeronautical Engineers, will be held on Saturday, March 27th, at 3.0 p.m. in the offices of the Society, 4, Hamilton Place, London, W.1.

AGENDA.

1. To read the Notice convening the Meeting.
2. To receive and deliberate upon the Report of the Council on the state of the Society and the Balance Sheets of Aerial Science Limited and Aeronautical Trusts Limited for the year ended December 31st, 1942.
3. To receive the nominations for Council for the years 1943-1945.
4. To announce the list of Fellows elected by the Council in accordance with Rule 4.
5. To elect the Auditors for the ensuing year for Aerial Science Limited and Aeronautical Trusts Limited.
6. Any other business.

By Order of the Council,

J. LAURENCE PRITCHARD,

Secretary.

Light refreshments will be served after the Meeting.

Associate Fellowship Examination, May, 1943.

Candidates for the May, 1943, Associate Fellowship Examination are reminded that entries must be in by March 31st, 1943.

Graduates' and Students' Section.

Members of the Graduates' and Students' Section are invited to the following lectures arranged by the Graduates' and Students' Section of the Institution of Automobile Engineers, 12, Hobart Place, S.W.1:—

Sunday, March 14th, 1943, at 3.0 p.m. Paper by Mr. J. H. Millward on "The Gearbox."

Sunday, April 11th, 1943, at 3.0 p.m. Informal Talk by Mr. L. Mantell on "The Practical Aspects of Thermal Efficiency."

Sunday, May 16th, 1943, at 3.0 p.m. Informal Talk by Mr. D. H. Bramley on "Works Organisation."

Conference on X-ray Analysis.

The Institute of Physics is arranging a second Conference on X-Ray Analysis to take place in Cambridge on April 9th and 10th next. The provisional programme includes a lecture on "Future Developments in X-Ray Crystallography,"

by Prof. J. D. Bernal, and discussions on " Quantitative Treatment of Powder Photographs," " The Fine Structure of X-Ray Diffraction " and " Fine Broadening." A report is to be presented to the Conference on the progress made in the preparation of an Index to X-Ray Diffraction Photographs, for which the Institute has undertaken to be jointly responsible with the American Society for Testing Materials and the American Society for X-Ray and Electron Diffraction.

Further particulars of the Conference and of the Index can be obtained on request from the Secretary of the Institute of Physics. (*Temporary Address*: At the University, Reading.)

Advertisements.

The fact that goods made of raw materials in short supply owing to war conditions, are advertised in the Journal, should not be taken as an indication that they are necessarily available for export.

Annual Subscriptions.

Members are reminded that their subscriptions were due on January 1st, 1943. The following are the current rates:—

	Home. £ s. d.	Abroad. £ s. d.
Founder Members	2 2 0	2 2 0
Fellows	4 4 0	3 3 0
Associate Fellows	3 3 0	2 2 0
Associates	*2 2 0	*2 2 0
Graduates (age 21-25)	2 2 0	2 2 0
,, (age 26-28)	2 12 6	2 12 6
Students	1 1 0	1 1 0
Companions	2 2 0	2 2 0

* £1 1s. 0d. without JOURNAL.

All those members who have relinquished their Journal have been notified of the reduction in their subscriptions due on January 1st, 1943.

The attention of members is drawn to Rule 55, as follows:—

> " Any Fellow, Associate Fellow, Associate, Graduate, Student, Companion or Founder Member. whose subscription shall not have been paid before the first day of April, shall be in arrears of subscription and shall not be entitled to attend or vote at any meeting or to receive any publications to which he would be otherwise entitled."

Election of Members.

Associate Fellows.—Alan Wickham Gifford Birch (from Graduate), John Crowe Bissett, Harold Alfred Carless, Frederick Cormack (from Student), Andre Marcel Desoutter, Frederick Anson Firth (from Associate), Raymond Hubert Garner, Ferdinand Fulton Greatrex (from Graduate), Kenneth Howard Greenly, John Hird (from Student), Peter Geoffrey Hodgkinson, Douglas Ivor Husk (from Graduate), Herbert Edward Le Sueur (from Graduate), James Lyall, William Leonard Morse, Dennis Anthony Cecil Nicholls, William Walton Rigbye, Ralph Squire Sorley, Thomas Leslie Sutton, Ronald Van Toen, Douglas Ian Vickery (from Graduate) Leonard Charles Ernest Waspe (From Graduate).

Associates.—Thomas Allitt, Ronald Lloyd Betts, Reginald Cecil Brooks, John George Henderson Brown, Victor George Bull, Roy Carnocnan, Benjamin Harry Caswell, William Ronald Cuthbert Evans, William Henry Hall, Leslie Samuel Austin Jones, John Morton Lake, Leonard William Lambert, Reginald George Lambourne, Ronald James Maccallum, Erick Manners, James Pritchett, Jagdish Rai Puri, Harold Royce, Edward Roland Skinner, Arthur Stanley Tite, Charles Keir Turner-Hughes, William Charles Wells, Harold Wilson, Kenneth Rolfe Woodcock.

Graduates.—Arthur Lionel Benns, Rex Anthony Harvey, Kenneth Walter Hetzel (from Student), Darrell William Jefferson-Loveday, Stanley John King, John Gareth Frank Lang (from Student), Robert Bulkeley Marsh (from Student), Ronald Rickard William Moss, Richard William Robert Osmotherby, Edwin Douglas Poppleton (from Student), Stanley Edward Richardson, Leonard Walter Steines.

Companions.—Alfred Brandt, Imrie Dodd (from Student), Maitland Heseltine Hall, Frank Midford-Millership, Leszek Szwarc.

Students.—Stephen James Andrews, Walter Leighton Norman Arthur, Samuel Berke, Peter Brett, Alexander John Chivers, William McAndrew Craig, John Derek Davis, Geoffrey Wallis Dearsley, Norman Albert Dimmock, Ernest Hobart, John Morris Jones, Norman Spencer Makins, Alfred Charles Martin, Andrew Derek Munro, Beryl Catherine Myatt, Gordon Charles Montague Parris, Donald George Pearce, Herman Sholom Pearlman, John Proctor Rayner, Vernon Heath Richards, John Keogh Sigournay, Leslie Sneesby, Reginald Speirs, Walter Henry Soutar, John William Stone, Norman Teather, Kenneth John Baddeley Teesdale, Gordon Heatherton Vokes, Stanley Warren, Percy Charles Wollen.

Additions to Library.

Pamphlets in italics with location reference following in brackets.
Books marked * or ** may not be taken out on loan.

*B.a.274-75.—Ministry of Aircraft Production Press Releases: Messerschmitt 210 A-1, No. 2 H-CA; Messerschmitt Me. 109 G-2. (Stencils.) 1943.

B.d.4.—*Aircraft Carriers of Great Britain, U.S.A. and Axis Nations. Real Photographs, Ltd.* 1942. 1/6. (PB.2.c.1.)

*B.g.121.—*The Book of the Wellington War Planes. Real Photographs, Ltd.* 1942. 1/3.

*B.g.122.—*Identification of Allied and Enemy War Planes. Real Photographs, Ltd.* 1942. 1/6.

*B.g.123.—*British and German Aircraft.* (3rd Ed.) *Gale and Polden, Ltd.* 1943. 1/6.

G.e.E.58.—*Rationalisation of Special and Alloy Steels to Meet Wartime Needs. Dr. W. H. Hatfield. Reprint from "Iron and Steel," Dec.,* 1942. (Y.13.c.S.)

L.d.86.—Navigation. J. C. Kingsland and D. W. Seager. Oxford University Press. 1943. 2/6.

*L.h.59.—Carte des Lignes Postales Aériennes Internes et Internationales. Bureau International de l'Union Postale Universelle. 1931.

M.a.26.—Radio. I. R. Vesselo and R. D. Morrison. Allen and Unwin. 1942. 2/-.

**R.b.236-39.—Four 19th century newspapers containing articles of aeronautical interest, as under:—

The Vauxhall Balloon and Parachute. (Cocking's.) "The Casket of Literature, Science and Entertainment," July 30th, 1837.

La Machine à Vapeur Aérienne. (Henson's.) "L'Illustration," April 18th, 1843.

La Catastrophe du Zénith. (Tissandier.) "L'Eclipse," April 25th, 1875.

Le Grand Ballon Captif des Tuileries. (Giffard's.) "La Presse Illustrée," July 28th, 1878.

**R.b.240.—The Dragon-Fly: or Reactive Passive Locomotion. Thaddeus Hyatt. Chas. Whittingham. 1882.

S.b.117.—Wings of War: an Illustrated Air Force Anthology. Ed. by F. Alan Warbank. 1943. 12/6.

*WB.21.—Journal and Proceedings of the Royal Society of New South Wales. Vol. LXXVI, Pt. 1. (1942.)

*X.c.M.18-22.—Technical Dictionary in Seven Languages. (5 Vols.) Ed. by Ernest Slater. Sir Isaac Pitman. 1928.

*UU.c.—*National Advisory Committee for Aeronautics (U.S.A.): Technical Memoranda*:—

No. 974. Boundary Layer Removal by Suction. O. Schrenk. (Luftwissen, Dec., 1940.)

No. 1,034. Aerodynamic Heat-Power Engine Operating on a Closed Cycle. J. Ackeret and D. C. Keller. (Z.V.D.I., May 31, 1941.)

No. 1,035. Control of Torsional Vibrations by Pendulum Masses. A. Stieglitz. (Jahrbuch D.L.F.F., 1938.)

No. 1,037. Theory of Heat Transfer in Smooth and Rough Pipes. G. D. Mattioli. (F.G.I., July-Aug., 1940.)

No. 1,038. The Performance of a Vaneless Diffuser Fan. V. Polikovsky and M. Nevelson. C.A.H.I., No. 224, 1935.)

No. 1,039. Pressure Distribution in Non-Uniform Two-Dimensional Flow. (Ingenieur-Archiv., Feb., 1935.)

Acknowledgments.

The Council acknowledge with grateful thanks the gift of the following books for the Library:—

The Dragon-Fly: or Reactive Passive Locomotion, by T. Hyatt (1882), presented by Mr. C. H. Coulton.

Technical Dictionary in Seven Languages (Pitman's, 1928), presented by Mrs. Fraser-Luckie.

Four 19th century newspapers containing historical articles; autographed sections from 2nd edition of Moedebeck's "Taschenbuch für Flugtechniker," etc., presented by Dr. F. J. Poynton.

The Council acknowledge also the gift of 5/- to the Endowment Fund, from Mr. D. K. Saunders, Student.

J. Laurence Pritchard, *Secretary and Editor.*

WOOD SMOKE AS A MEANS OF VISUALISING BOUNDARY LAYER FLOW AT HIGH REYNOLDS NUMBERS.

By J. H. Preston, B.Sc., Ph.D., A.F.R.Ae.S., and N. E. Sweeting, of the Aerodynamics Department, N.P.L.

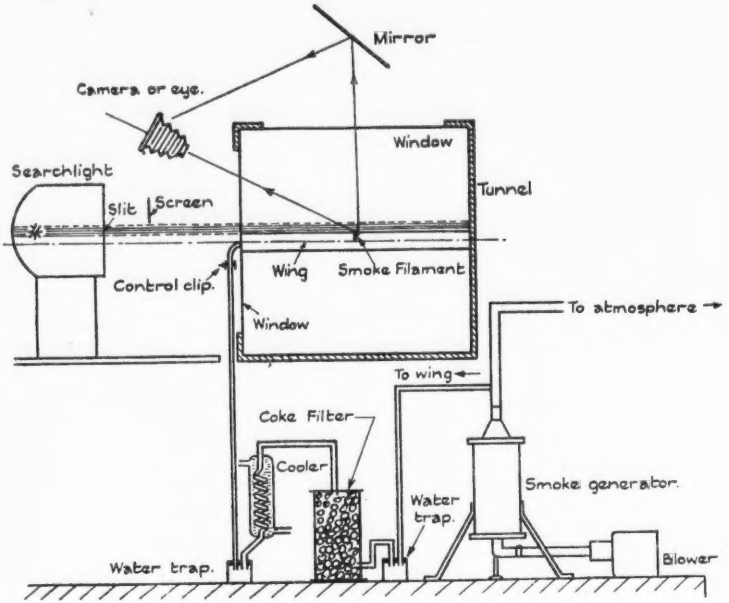
1. Introduction.

Modern research in experimental aerodynamics is largely concerned with the effects of the boundary layer. Interpretation of experimental results would be greatly assisted by the knowledge of the position and extent of the transition region and of the separation points. Frequently this has to be obtained, and it can only be done by the use of an elaborated technique involving hot-wires or total head creepers with complicated traversing gear, so that the work takes on the character of a major research.

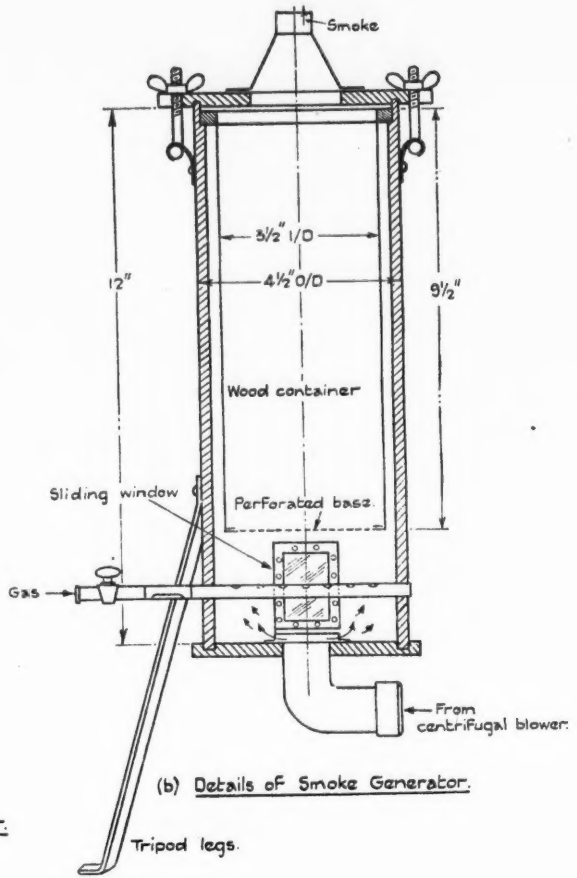
Experiments in the water-tunnel by Fage (1, 2) and one of the present authors, made use of coloured liquid (white ink) as an indicator. This was carefully introduced into the boundary layer near the nose of the model, so as not to interfere with the flow over the surface. By this means, which was both simple and rapid, it was possible to locate separation points, and transition points or regions; and to obtain at a glance a general impression of the flow up to Reynolds numbers of the order of 10 (6), which non-visual methods fail to give.

The idea was put forward as long ago as 1928 by B. M. Jones (3), in connection with transition phenomena on airships, that smoke introduced into the boundary layer would indicate the transition point, because the essential characteristic of a turbulent flow is its power of diffusion, so that when transition occurs the smoke will be diffused much more rapidly than by molecular processes. The water tunnel experiments confirmed B. M. Jones' idea and the technique developed there has now been applied to experiments in air.

In the past attempts have been made to use chemical smokes for visualising air-flow, but with one or two exceptions these have been mainly for instructional purposes at low speeds and in small wind tunnels. Simmons and Dewey (5) succeeded in photographing the flow in the boundary layer of a flat plate at Reynolds numbers of the order of 10 (6) by the use of titanium tetra-chloride, but found that solid deposits prevented its use for any length of time since it was necessary to deposit liquid titanium tetra-chloride in a groove on the surface as tubes rapidly choked up. Most dense chemical smokes suffer from this disadvantage and in addition are frequently corrosive and poisonous. Further they are difficult to keep and are usually expensive. Thus the problem of visualising airflow in the boundary layer essentially turns on obtaining a sufficiently dense, non-corrosive, non-poisonous smoke, free from solid deposits, which can easily be made and controlled. Fortunately this problem has been solved. Lippisch (4) in taking a remarkable film, used a smoke made from rotten wood. This was filtered and cooled and then led to a multiple jet or nozzle from which issued several dense and brilliant filaments of smoke equally spaced, which flowed past model wings in a narrow channel. The resulting picture is very similar to that produced in a Hele-Shaw apparatus, except that eddies were formed in the wake and Reynolds numbers of the order of 10 (6) could be obtained. No details of the wood used or of the stove for burning it were given. A brief search showed that quite recently a similar apparatus had been built in the U.S.A. by Griswold (6), though again no details were available regarding the smoke. The apparatus described below was made up as a trial.



(a) General Arrangement of Apparatus.



(b) Details of Smoke Generator.

Apparatus for Rendering visible the Flow in the Boundary Layer.

FIG. 1.

2. Description of Smoke Producing Apparatus.

A sectional view of the apparatus is shown in Fig. 1b. It may be described as a smoke generator, and it consists of an external jacket made from a length of cast iron water main, which is sufficiently thick to ensure that the attachments of the lid and other fittings are robust and simple. Inside this a cylindrical container of thin sheet iron is fitted so that an air gap exists between it and the outside jacket and so acts as lagging. This container is designed to be removable and is a close fit at the top so that all the air supplied by the blower connected to the bottom of the cast iron cylinder passes through the container which is perforated at the bottom. Dry rotted wood is crumbled into small pieces and loosely packed into the container. The wood used in the present experiments was that from a dead apple-tree. In appearance it was white and was silky in texture. It was easily crumbled and very light. The smoke produced from this under a fairly strong draught was very white and dense and almost pleasant to breathe. Under a very slight draught the density fell off and an attempt was made to improve this by impregnating the wood with a weak solution of potassium nitrate and then drying it, but without result. It is possible that heating the air before it reaches the wood might improve the density for small draughts. Sawdust was tried as an alternative to rotten wood, but the smoke was not so dense and much more wet and acrid. It is not thought that there is any particular advantage in the use of apple-tree wood; any wood which has rotted to a similar condition ought to serve equally well, though this is a matter for further experiments.

To ignite the wood a gas jet was built into the stove so that the flame plays on the perforated base. When this is being done the lid is removed and the blower run very slowly. A sliding mica window enables the flame to be lit and watched. (If no gas is available the combustion of the wood can be started by heating the container over a spirit flame and then quickly placing it in the jacket with the blower running.)

As steam and tarry distillates are given off during the slow combustion of the wood, water-traps are necessary; and as a further precaution against stoppages, the smoke passing to the model is filtered through broken coke contained in a small oil drum; and then passed through a cooling coil surrounded by a water jacket so that it emerges at room temperature.

3. Experimental Technique.

The smoke is introduced into the boundary layer through a hole in the surface of the model at the desired position. To ensure that this is in the laminar part of the boundary layer it should be near the nose. If desired, a number of holes at different parts of the model can be used and smoke filaments from these viewed simultaneously. If pressure plotting tubes have been let in, these can be used, if their internal bore is fairly large, so that there is no danger of blockage by moisture. In the experiments described later a run of " compo " tubing $\frac{3}{8}$ in. diameter internal bore was let into the model so that near the nose it ran for a short distance parallel to the L.E. The end was blocked and a slit $\frac{1}{4}$ in. long and $\frac{1}{16}$ in. wide was cut into the tube. The downstream edge of this slit was slightly eased so that a stronger filament could be maintained without disturbing the flow. Rubber tubing connected the " compo " tubing to the cooler and this was kept as large as possible to prevent stoppages. Owing to the fact that only a small volume of smoke is actually introduced into the boundary layer, and that a large volume must be produced if it is to be dense, it is necessary to run the blower fairly fast and to by-pass most of the smoke, so produced, out of the window to atmosphere.

Careful attention must be given to the lighting. In order to make the filament stand out, a chordwise strip of the model about 6 in. wide was painted matt black and any roughness was carefully removed with fine sand-paper. After a number of trials it was found that approximately grazing lighting gave the

best results when the filament was viewed from the same side as the lights (see sketch Fig. 1a), the filament standing out white and luminous against the dark background. It is essential to use a powerful light and to screen the unwanted parts of it in order to obtain maximum contrast. In the present experiments a small search-light with a 15 in. reflector taking 10-15 amps. at 110 volts was used. It was arranged as shown in the sketch, Fig. 1a. If it is desired to take photographs, precautions must be taken to get rid of troublesome reflections in the window of the wind-tunnel.

A few notes on the operation and appearance of the smoke filament will now be given. The blower is run to give smoke of satisfactory density and the wind-tunnel is run at a convenient low speed. The screw clip on the rubber tube leading the smoke to the model is opened fairly wide and the smoke allowed to issue, as a highly diffused jet, into the airstream. The clip is now gradually screwed up until the smoke suddenly appears as a dense parallel filament lying on the surface. The wind can now be increased to the desired speed and observations taken. In general it is desirable to cut down the strength of the filament to the minimum consistent with easy viewing, in order to avoid disturbing the flow. Such disturbances are easily seen as tremors occurring in the filament. If the speed is low, the laminar filament will persist until laminar separation occurs, when the filament leaves the surface. Close observation will reveal wisps of smoke being swept against the stream, and it is not difficult to fix the separation point accurately. The filament is generally visible for some distance behind the separation point and it marks the edge of the dead-water or eddying region caused by the separation. As the speed is increased the separation point, in general, moves back slightly and the thickness of the " dead-water " region is reduced while the length of the filament visible after separation gets shorter. A speed is finally reached at which no details of separation are visible, the filament is more or less suddenly broken up and diffused, depending on the turbulence in the stream, pressure gradients and Reynolds number. We have now a transition to turbulent flow taking place near the point of laminar separation. By careful attention to background and direction of lighting it is possible to distinguish this diffused band of smoke in its progress over the tail of the model. If the tail is not too bluff this diffused band clings to the surface of the model. On a bluff-tailed wing it is possible to observe with reasonable accuracy the point of turbulent separation, i.e. where this diffused band leaves the surface. At higher speeds the transition point or region may move forward—depending on tunnel turbulence, pressure gradient, Reynolds number and surface finish. Observations in the water tunnel have shown that transition is a sudden phenomenon occurring at any point in the transition region in a haphazard manner. Near the beginning of the transition region the filament is rarely broken up, whilst near the end of the transition region the filament is rarely seen, and beyond that it is completely dispersed. Details are much more difficult to follow in a wind tunnel. Owing to the increased speeds of flow and the large erratic disturbances present in addition

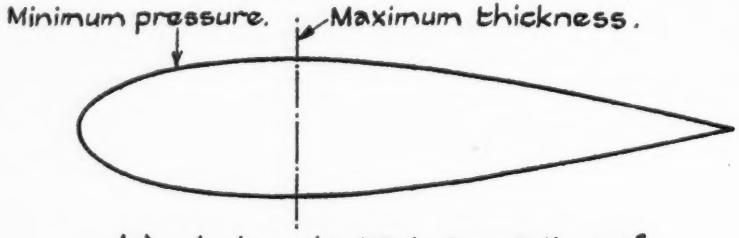
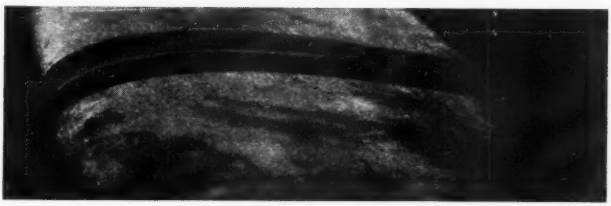


FIG. 2.

(*b*)

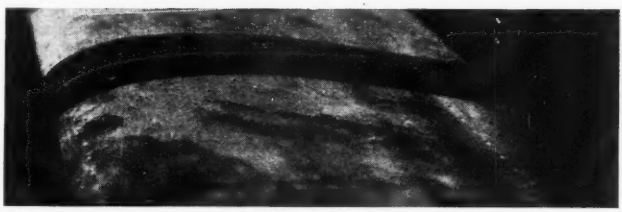


L.E. $V = 10$ *ft./sec.*

(*c*)

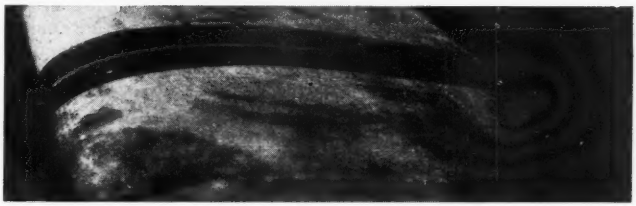
$V = 20$ *ft./sec.*

(*d*)



$V = 40$ *ft./sec.*

(*e*)



$V = 60$ *ft./sec.*

FIG. 2.

Boundary Layer Flow Experiments in 4 ft. No. 2 Tunnel.

to general turbulence in ordinary wind tunnels, the precise determination of the transition region is a matter of difficulty, though its average position can be located. High speed cine-photography might help. If the tunnel turbulence is small, it would appear that in the turbulent part of the boundary layer, the thickness of the diffused band of smoke in this region should correspond to the boundary layer thickness, since beyond the edge of the boundary layer the turbulence is small and diffusion will be small.

4. Illustrative Experiments.

These were carried out to put the wood smoke and the technique gained in the water tunnel to severe practical tests. The 4 ft. No. 2 Tunnel was available and this has recently been fitted with a Cambridge type (triangular cells) honeycomb. According to Mr. Simmons this has reduced the turbulence at the working section to about one-third of that for the ordinary honeycomb. The value of u'/U at the working section is now 0.005 to 0.006. The experiments described under (c) were made in 7 ft. No. 3 Tunnel, which is more turbulent, but enables larger models to be used.

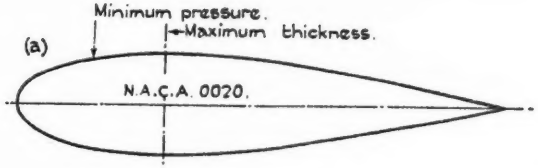
(a) The first model was the Generalised Joukowski section No. 4 described in R. & M. 1241. It is approximately 20 per cent. thick and the chord of the model was 14.5 in. The surface of the model was not in very good condition, so the centre portion under observation was smoothed with sand-paper. The model was set at 0 degree incidence.

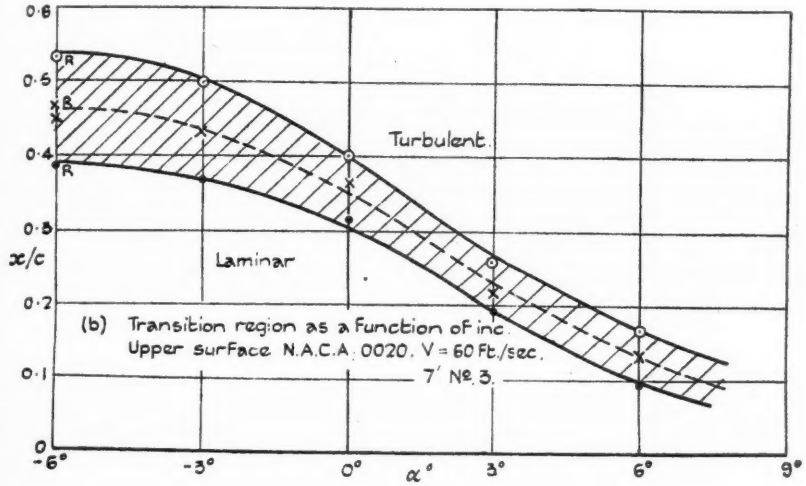
Below 20 ft./sec. there was a well defined laminar separation (see Fig. 2b) which occurred at approximately 0.35 chord from the L.E. Associated with this was the usual dead-water region. As the speed approached 20 ft./sec. the separation point moved slowly back and the dead-water region gradually disappeared, so that at this speed, laminar separation gave way to transition at about 0.6 chord from the L.E. (see Fig. 2c). The diffused smoke in the turbulent boundary layer followed the surface there being no turbulent separation. Increase of speed brought about a slow forward movement of the transition point. Figs. 2d and 2e show views at 40 and 60 ft./sec. There was no evidence of a transition region though there is a short region before the filament is finally dissipated in which the filament and the flow is somewhat confused. The views shown here resemble those seen in the water tunnel without a turbulence grid. Increase of speed up to 75 ft./sec. brought about no further change in the character of the flow. The pressure minimum for this section (see R. & M. 1241) occurs at 0.15C. from the L.E., so it is remarkable that laminar flow is maintained so far against an adverse pressure gradient at high tunnel speeds. It would seem that the turbulence is almost small enough to be negligible.

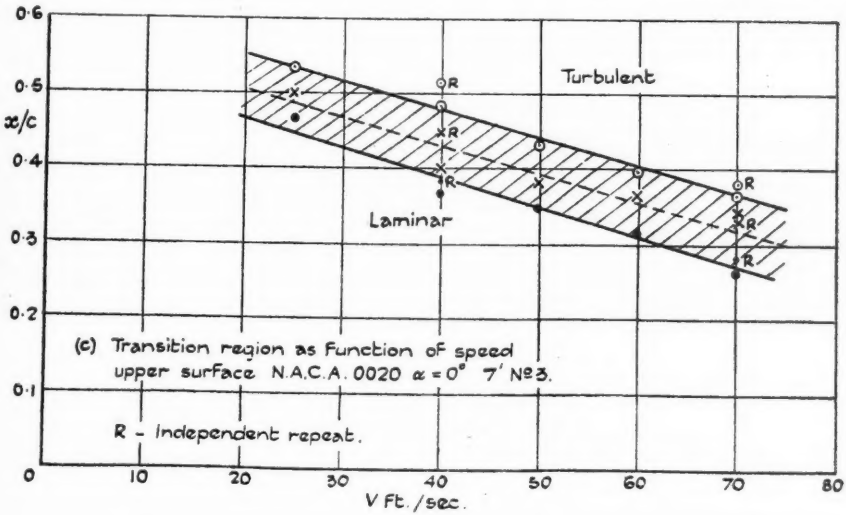
(b) The flat plate used in the Compressed Air Tunnel experiments, described in R. & M. 1804, was carefully set to 0 degree incidence. This plate was of 2 ft. chord and $\frac{1}{8}$ in. thick. It had an elliptical nose ($a/b = 4 : 1$) and a biconvex arc tail, commencing 1 in. from the T.E. A small hole was tapped into the surface and a tube screwed in from the lower surface. Only a weak filament could be produced from this hole without upsetting the flow because of the small circular hole from which the smoke issued. This, whilst satisfactory for visual purposes, was rather weak for distinct photographs, except perhaps at low speeds. Up to 60 ft./sec. there was laminar flow along the complete length of plate. The filament was perfectly still and on the surface and appeared more like a thick, straight wire than a filament of smoke. At this speed the filament had to be very weak to avoid disturbing the flow. Above this speed the filament appears to break down frequently from about the half chord position—there was no gradual creep of a transition point or region. The impression was formed that this break-down was due to large disturbances not associated with the turbulent shed from the honeycomb.

(c) The method has been applied to a 30 in. chord N.A.C.A. 0020 symmetrical section 20 per cent. thick, in the 7 ft. No. 3 Tunnel. This tunnel is fairly turbulent (Sphere No. $= 2.1 \times 10$ (5) and the Reynolds number at top speed for a wing of this chord is 1.2×10 (6), so that an extremely severe test of the usefulness of the method can be made.

The wing completely spanned the tunnel and compo tubing was let into the surface parallel to the L.E. and about 2 in. from it. The test section was chosen, for convenience, slightly nearer the door than the centre of span. It was painted matt black and white lines, indicating every inch as well as 0.1 chord, were drawn. The whole was carefully rubbed smooth with fine sand-paper. As the







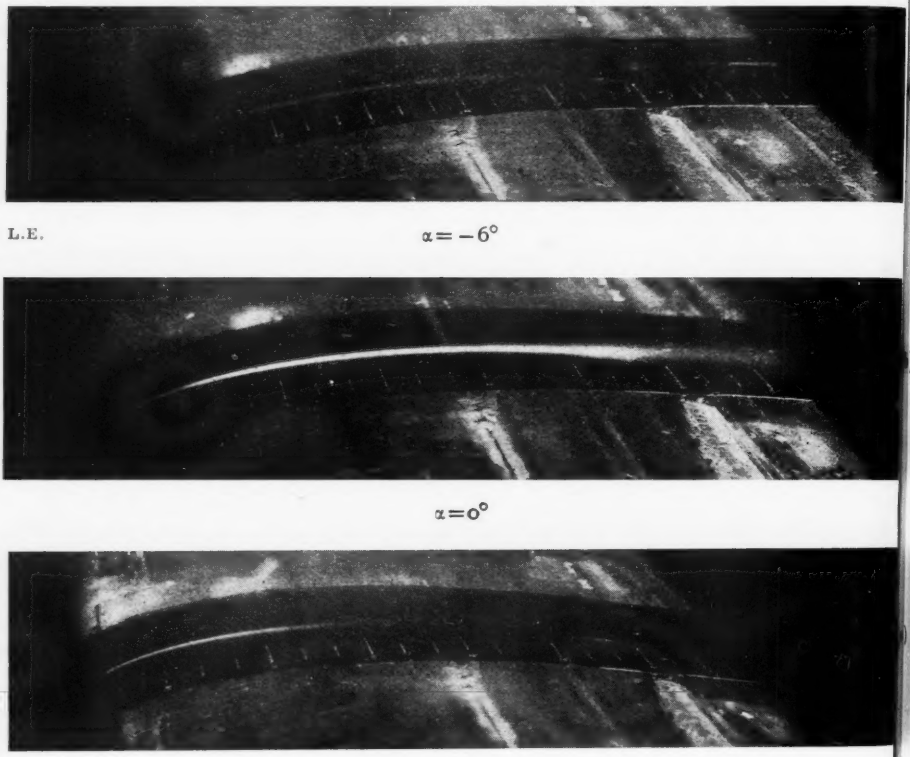
Transition Experiments on N.A.C.A. 0020 Aerofoil in 7′ Nº 3 Tunnel.

FIG. 3.

Transition Experiments on N.A.C.A. 0020 Aerofoil in 7 ft. No. 3 Tunnel.

wing was symmetrical, one surface only was observed at positive and negative incidences of 3 degrees, 6 degrees as well as 0 degree, and over a range of speeds from 25 ft./sec. to 70 ft./sec.

It was possible to estimate the last position at which traces of a laminar type filament were seen. It is necessary to wait for a minute or two as this occurs but rarely, though it is relatively easy to observe. This is defined as the end of the transition region (1, 2). The position at which the laminar filament is most frequently being broken up is taken to define the mean position of the transition region, and the point nearest the nose at which a break-up of the laminar filament occurs is taken as the beginning of the transition region. It is possible that the results obtained here under-estimate this position at the higher speeds, as



Boundary Layer Flow Experiments in 7 ft. No. 3 Tunnel.

FIG. 4.

N.A.C.A. 0020 Aerofoil. V = 25 ft./sec.

transitions occur so rapidly that the eye cannot follow them. At negative angles of incidence observation was more difficult and the transition region much more extensive than at positive incidences. This is due to the much smaller pressure gradient along the surface at a negative incidence which allow the fluctuating pressure gradient, associated with turbulence to bring about transient separation (transition) over a bigger region.

Typical results are shown plotted in Figs. 3b and 3c, which show the forward movement of the transition region with increase of incidence and speed and give some idea of its extent.

Fig. 4 shows photographs of the filament taken at 25 ft./sec. at incidences of -6 degrees, 0 degree and 6 degrees; whilst Fig. 5 shows the filament at these incidences at 60 ft./sec. The exposure was of the order of half-minute so that the transition region is represented by the gradually reduced density of the filament. High speed cine-photography would be necessary to photograph details of the transition. A suitable camera would be that described by Lippisch (4), taking over 1,000 pictures a second.

L.E. $\alpha = -6°$

$\alpha = 0°$

$\alpha = 6°$

FIG. 5.

N.A.C.A. 0020 Aerofoil. V=60 ft./sec.
Boundary Layer Flow Experiments in 7 ft. No. 3 Tunnel.

5. OTHER APPLICATIONS.

The method might be of service in the numerous fairing problems associated with particular aircraft by aiding in the detection and prevention of turbulent separation with consequent drag reductions.

Stalling, particularly wing-tip stalling, might be studied with the aid of this apparatus. It may be mentioned that some preliminary experiments on a 30 in.

chord 10 per cent. thick aerofoil in the 7 ft. No. 3 Tunnel showed that details of the stall could be plainly seen at high speeds.

Flow through ducts, slots, etc., could be rendered visible by the use of this smoke, and it would be ideal in large scale ventilation problems as it can be produced in any quantity and is neither corrosive nor obnoxious.

6. Acknowledgments.

The work described above was carried out in the Aerodynamics Department of the National Physical Laboratory, and it is published on the recommendation of the Aeronautical Research Committee and by permission of the Director of the Laboratory.

Mr. S. P. Linden made and assisted in the design of the smoke generator, Mr. T. W. Brown assisted with the observational work, and Miss V. M. Emms took the photographs.

7. Summary and Conclusions.

The technique of visual observation of the flow in the boundary layer as developed by Fage (1, 2) and one of the present authors, in the water tunnel at the N.P.L., has been successfully applied to the flow of air in the boundary layers of wings at high Reynolds numbers. The method in principle is identical with that suggested by B. M. Jones (3) in R. & M. 1199 (1928). The disadvantages associated with chemical smokes have been overcome by the use of wood smoke—in fact the success of the method is due almost entirely to its use. The apparatus and method of generating the smoke is simple and inexpensive and originally due to Lippisch (4). The amount of smoke in the tunnel room even after long periods of running is scarcely noticeable, and its odour in contrast to chemical smokes is almost pleasant, whilst corrosive or irritant action is non-existent. The density of the smoke, given suitable illumination, is sufficient for both visual and photographic work at high speeds. In the short time available there has been no opportunity to improve this and in the opinion of the authors this could be done and might be necessary if high speed cine-photography were attempted.

The technique described in the present report gives a rapid means of locating laminar separation, transition points or regions, turbulent separation, and enables an idea to be formed of the thickness of the turbulent boundary layer. Location of the beginning of the transition region is difficult when the stream is very turbulent, but this is the case whatever method is used. For investigations not concerned with quantitative details of flow in the boundary layer, such as the velocity profiles, etc., the present method should be satisfactory and might be of service to operators of commercial wind tunnels. Where such details are required, use of the present method would be hot wires or total head tubes and would assist the interpretation of the measurements.

There is no reason why the method should not prove useful at much higher Reynolds numbers than those in the experiments described here, provided the turbulence is small.

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DETERMINATION OF THE BUCKLING LOAD OF STRUTS WITH SUCCESSIVE APPROXIMATIONS.

By Dr. J. Ratzersdorfer, A.F.R.Ae.S.

In cases of tapered struts with hinged or built-in ends where the exact determination of the buckling load is complicated it may be useful to apply a method of successive approximations.*

Let us first consider a bar of the length l with hinged ends under the action of the compressive force P. The differential equation of the bending line becomes

$$EI(u)\frac{d^2v}{du^2}+Pv=0 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where v is the deflection at the section u, v with the moment of inertia $I(u)$ and E is Young's modulus. At the ends of the bar the deflection v is equal to zero (Fig. 1).

Instead of the differential equation we take the finite differences equation and solve the problem by successive approximations. We divide the length l in $k+1$ equal parts $\xi=l/(k+1)$ and by using the notation

$$a_i^2=\frac{P}{EI_i}=\left(\frac{P}{EI_m}\right)\left(\frac{I_m}{I_i}\right)=a_m^2\left(\frac{I_m}{I_i}\right)$$

we get

$$\left(\frac{1}{\xi^2}\right)(v_{i-1}-2v_i+v_{i+1})+a_i^2v_i=0$$

or

$$v_{i+1}=v_i(2-a_i^2\xi^2)-v_{i-1}, \text{ where } i=1, 2, 3 \ldots k \quad . \quad . \quad (2)$$

This formula represents a system of k homogeneous linear equations under the boundary conditions $v_0=0$, $v_{k+1}=0$.

By putting the determinant equal to zero the condition for $a^2_m=P/(EI_m)$ is found. Herewith for a series of values $k=1, 2, 3, \ldots$ successive approximations to the critical a_m^2 are obtained.

We use system (2) to calculate the critical value by the method of trial-and-error. For an assumed value k we take a value a_m^2. In the first equation (2)

$$v_2=v_1(2-a_1^2\xi^2)-v_0$$

v_0 equals zero according to the boundary condition. We set $v_1=1$ and determine v_2. (Since all the deflections v change in proportion to v_1 we can take any value for v_1.) The second equation

$$v_3=v_2(2-a_2^2\xi^2)-v_1$$

gives now v_3, the third equation v_4, etc. From the last equation

$$v_{k+1}=v_k(2-a_k^2\xi^2)-v_{k-1}$$

we then obtain v_{k+1}. The value a_m^2 is to be chosen so that v_{k+1} is actually equal to zero.

If the bar is built-in on both ends then the differential equation of the bending line becomes

$$EI(u)\frac{d^2v}{du^2}+Pv+M=0 \quad . \quad . \quad . \quad . \quad . \quad (3)$$

* See also writer's book: Die Knickfestigkeit von Stäben und Stabwerken (Buckling of Bars and Bar Systems), p. 117, Vienna, 193 , and his paper in R. Katzmayr's Beiträge zur Flugtechnik, p. 36, Vienna, 1937.

where v is the deflection at the section u, v and M the bending moment at the built-in ends. At these ends v is zero and so is the slope dv/du of the deflection curve. For the moment we can, considering the sign, put down the equation

$$M = -EI_o\,(1/\xi^2)\,(v_1 - 2v_o + v_{-1})$$

With the boundary conditions $v_o = o$ and $v = v_{-1}$ we get now the term

$$M = -EI_o\,(2v_1/\xi^2)$$

The finite differences equation which we develop from Eq. (3) has with the previous abbreviation

$$a_i^2 = \frac{P}{EI_i} = a_m^2\left(\frac{I_m}{I_i}\right)$$

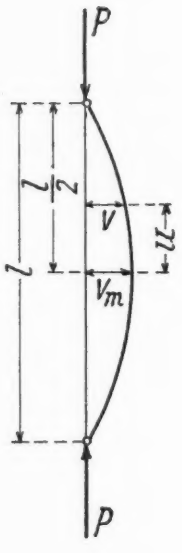

FIG. 1.

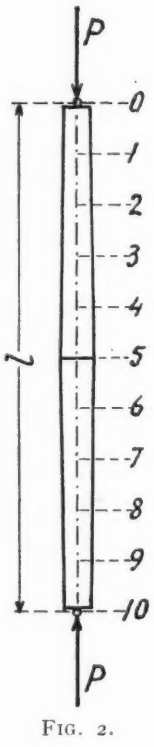

FIG. 2.

the form

$$\left(\frac{1}{\xi^2}\right)(v_{i-1} - 2v_i + v_{i+1}) + a_i^2 v_i - 2\left(\frac{I_o}{I_1}\right)v_1 = o$$

or

$$v_{i+1} = v_i\,(2 - a_i^2\xi^2) - v_{i-1} + 2\,(I_o/I_1)\,v_1, \text{ where } i = 1,\ 2,\ 3,\ \ldots\ k \quad . \qquad (4)$$

This equation is to be solved as described above.

To illustrate the method let us consider an example. The moments of inertia of the cross-section of a strut with hinged ends have a symmetrical course and follow the quadratic

$$I = I_m\,(1 - 0.7351\,u/l)^2$$

In the middle we have $u = o$, $I = I_m$ and at the ends $u = l/2$, $I_1 = 0.4\,I_m$ (Fig. 2).

For $k=9$, *i.e.*, by division in 10 equal parts we have $\xi=l:10$ and

$$a_1^2=2.0065\ a_m^2,\ a_2^2=1.6459\ a_m^2,\ a_3^2=1.3744\ a_m^2,\ a_4^2=1.1650\ a_m^2,$$
$$a_5^2=a_m^2=P/(EI_m).$$

The boundary conditions are $v_0=0$ and $v_{10}=0$ or for reasons of symmetry $v_6=v_4$. We take $a_m^2l^2=7.50$ and hence we get from Eq. (2) with $v_0=0$, $v_1=1$,

$$v_2=1.8495,\ v_3=2.4705,\ v_4=2.8367,\ v_5=2.9550,\ v_6=2.8517.$$

The difference v_6-v_4 is equal to 0.0150 instead of zero. With $a_m^2l^2=7.60$ we find

$$v_2=1.8475,\ v_3=2.4638,\ v_4=2.8226,\ v_5=2.9313,\ v_6=2.8172,$$

and $v_6-v_4=-0.0054$. The interpolation gives $a_m^2l^2=7.574$ and, therefore, the buckling load

$$P_{cr}=7.57\ (EI_m/l^2)$$

with an error of approximately 0.5 per cent. compared with the exact value $7.61\ (EI_m/l^2)$.*

For $k=3$, 5, 7, the coefficients 7.43, 7.52 and 7.56 are obtained. It is to be seen that with an increase in the number of parts the accuracy of the approximation becomes increasingly better. When the results for two consecutive values k are very close together we may conclude that a new trial is unnecessary.

Supposing the ends of the strut are built-in. At first we take $\xi=l:10$. To our previous data we have to add:—

$$I_0:I_1=0.8026,\ I_0:I_2=0.6583,\ I_0:I_3=0.5498,\ I_0:I_4=0.4660,\ I_0:I_5=0.4.$$

In the same way as before we get by using formula (4) the critical load $P_{cr}=24.5\ (EI_m/l^2)$. By dividing the length l in twenty parts, *i.e.*, $\xi=l:20$, we obtain

$$P_{cr}=25.27\ (EI_m/l^2)$$

whilst the true value has the coefficient 25.54 and is, therefore, about 1 per cent. greater.*

The method is also applicable to the solution of the differential equation that results when the loads are continuously distributed along the length of the strut.

REVIEWS.

WINGS OF WAR: AN ILLUSTRATED AIR FORCE ANTHOLOGY.
Edited by F. Alan Walbank. B. T. Batsford. 1943. 12/6.

This title is, perhaps, misleading, for it is stretched to cover experimental machines designed long before the R.A.F. existed, the pure phantasies of H. G. Wells, and a number of sporting ventures undertaken by Service personnel or in Service machines—such as the Schneider trophy races and the privately financed Everest flight. But we will not quarrel with Mr. Walbank on this account, for he has chosen his extracts, both prose and poetry, with a nice discrimination and a due feeling for their literary value. They follow a definite chronological pattern, from the early days, through the 1914 war and the intervening period, to the present time. The illustrations are plentiful and good, and a careful index adds to the value of the book.

As with all anthologies, each reader will single out what appeals to his personal taste. The reviewer—with the handicap of having already read most of the extracts in their original setting—particularly enjoyed those which were new to him: Winston Churchill's account of his first flight; Sir John Squire's poem, "Airship over Suburb"; Sagittarius' parody of "Innisfree" (p. 107); and John Masefield's epitaph "To a Young English Airman." The last sentence of the quotation that closes the book is especially good: "A touch of that evaporating ecstasy is still on him as he walks to the hangars before joining the

* The accurate value has been calculated by A. N. Dinnik. Design of Columns of Varying Cross Sections. Transact. of the American Society of Mech. Engineers, 1928. Westnik Ingenerow, 1929

others for tea." . . . Ecstasy and tea—could the two ideas be combined anywhere but in England? And the fact that they can be so combined is a high-light on that English character which so completely puzzles our friends and baffles our enemies.

NAVIGATION.

By J. C. Kingsland and D. W. Seager. Oxford University Press. 1943. 2/6. (Series: Oxford Air Training Manuals.)

Here is yet another manual for the A.T.C. cadet, closely following the pre-war 2nd Class Navigator's syllabus: Form of the Earth, Maps and Charts; Magnetism and Compasses; "Meteorology" (in this case used as a synonym for a paragraph or two on atmospheric pressure and its effects on instrument readings), and Dead Reckoning Navigation. In less than 100 pages, the authors contrive to impart a good deal of useful information. The chapter on Magnetism is particularly clear, and so is the explanation of the effect of pressure changes on Altimeter readings—a subject which is of vital importance to the prospective pilot, and is only too frequently presented in such a way as to leave him altogether bemused. The diagram illustrating the effect of temperature differences on altimeter reading (Fig. 38) is admirable. There are a number of exercises, to which answers are given at the end of the book.

RADIO.

By I. R. Vesselo and R. D. Morrison. Allen and Unwin. 1942. 2/-.

This new publication in the "Air Cadets' Handbooks" series may with advantage be read as a "second step" by those who have worked through the handbook on "Elementary Electricity" reviewed in our February issue. The first 50 pages give an outline of Electricity and Magnetism, followed by an explanation of radio valves and some typical transmitters and receivers. In the last two chapters we have a brief description of the principles of aircraft radio: fixed and trailing aerials, direction-finding, and a few notes on the plotting of radio bearings and the errors to which they are subject. We suggest that, in the section on Magnetism, it is preferable to use the terms "Blue" and "Red" poles, as the geographical connotation of "North" and "South" Pole is apt to confuse a beginner. The book would also be improved by more diagrams in the section on "Radio as an Aid to Navigation." This section is introduced by the sentence: "Bearings obtained by radio are subject to certain errors which must be clearly understood," but in our opinion the description of Quadrantal Error, Coastal Refraction and Night Effect is simplified to the point where it would only be "clearly understood" by those readers who already knew what the authors were talking about.

CORRESPONDENCE.

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

February 5th, 1943.

Dear Sir,—Many will thank you, Sir, for publishing, and Mr. Manley for writing, the articles on vibrating systems which appeared in your January number. We who teach, and others, echo Mr. Manley's strictures upon the muddle which has arisen owing to the injudicious use of the term "mechanical impedance." It does, however, seem a pity that in these articles (and in his book) Mr. Manley did not criticise constructively by adding his voice to those who do use this term to denote a quantity precisely analogous to the electrical impedance.

Mr. Manley defines

$$\text{dynamic stiffness} = \text{force} \div \text{displacement},$$
$$\text{effective inertia} = \text{force} \div \text{acceleration}.$$

Neither of these has, for the general electric circuit, an analogue which the electrical engineers are in the habit of using. But mid-way between them is another quantity—

$$\text{force} \div \text{speed},$$

which is analogous to

$$\text{voltage} = \text{current} \div \text{impedance},$$

and so can rightly and usefully be termed "mechanical impedance."

The present writer sincerely hopes that the above use of the trinity "dynamic stiffness," "mechanical impedance," and "effective inertia," with the above definitions, can rapidly become standard.

Yours faithfully,

W. G. BICKLEY.

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

"Kvik Michael," Hillfield Road,
Farnborough, Hants,
3rd February, 1943.

"ELECTRO-MECHANICAL ANALOGY, ETC."

Dear Sir,—It is puzzling that Mr. R. G. Manley should have been unable to find a full description of the electro-mechanical analogy or, to be more precise, analogies. There is an extensive literature, especially in the English language, and most text books give it as much detail as it requires or deserves. In view of the paper shortage, I will not give a bibliography, but will suggest study of the yearly indexes of Science Abstracts (A and B).

The main difficulty about these analogies is to discover what purpose they serve, as usually employed. If they are used, as in fact they sometimes are, for the construction of computing apparatus their value is obvious, but such applications are rarely mentioned.

If the purpose is to enable electric circuit notation to be used for mechanical systems, then the analogy proposed by Mr. Manley largely defeats itself. By identifying mass and inductance, one is forced to represent mechanical elements in series by electrical elements in parallel, a rich source of blunders.

If, however, we identify inductance with spring and capacity with mass, this difficulty disappears, and the mechanical and electrical diagrams are identical, as are of course the equations. This being so, there seems little reason in calling in electricity at all, unless one is building a computor.

The main exponent of this last system is Dr. F. A. Firestone, who has described its application in many sources.*

Yours faithfully,

R. A. FAIRTHORNE.

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

February 22nd, 1943.

Dear Sir,—The universal adoption of Dr. Bickley's suggested definition of "mechanical impedance," and of the resulting complete trinity of quantities, would be most advantageous to all who use or teach the theory of vibration. The connotation which we should like to abolish has been the result of usage, and it is unfortunately a fact that the most admirable changes in usage are the most difficult to accomplish; such difficulties should not, however, discourage the attempt to place the terminology of a science upon a rational basis, and I concur entirely in Dr. Bickley's expressed hopes for a rapid standardisation. There are other anomalies which should be eliminated; it is surprising, for example, how many writerss refer to the "centre of gravity" and "moment of inertia" of cross-sections which (being merely areas) are not influenced by gravity and have

* (inter alia) J. App. Phys. J., 6, pp. 373/87. "The Mobility Method of Computing the Vibration of Linear Mechanical and Acoustic Systems, etc." F. A. Firestone.

no inertia. The time has come for scientists and technicians to follow Mr. A. P. Herbert's advice and " worry about words."

Dr. Bickley's suggestion raises a question of some practical importance; would it not be advantageous to adopt the quantity which we agree to call " mechanical impedance " as a practical measure of vibration characteristics, in place of dynamic stiffness or effective inertia? The method of determining resonant frequencies by the intersection of characteristic curves has been developed mainly by aeronautical engineers; some such development was in fact necessitated by the inertia-plus-flexibility properties of the modern metal propeller. Now, it is immaterial, as far as results are concerned, which member of Dr. Bickley's trinity is selected for this purpose; and although mechanical engineers tend to think in terms of inertias and displacements rather than in terms of velocities, the adoption of a velocity basis of measurement would actually effect the elimination of a piece of apparatus; the electromagnetic torsiograph used in the practical determination of the dynamic stiffness of propellers gives an output voltage proportional to velocity, and this output is generally passed through an integrating device in order to obtain a measure of the displacement. This integration is, of course, unnecessary if the velocity measurements are required instead of displacement measurements.

It might be argued that the retention of the torsiograph as a displacement-measuring instrument is necessary for the calculation of T.V. stresses; it is now quite clear, however, that the presence of " rolling " components in the torsional vibration of crankshaft systems precludes the possibility of obtaining correct values for stresses by calculation from observed displacement-amplitudes at either end of the crankshaft, and that reliable results will only be obtained by the use of strain gauges.

I am grateful to Dr. Bickley for his suggestion, and trust that it will receive the consideration of other interested persons and so initiate the development of a standardised terminology and technique.

Replying to Mr. Fairthorne's points in order: No *complete* ab initio treatment of the analogy is given in the standard works on mechanical vibrations (Den Hartog, Timoshenko, Ker Wilson), although Den Hartog supplies a table of analogous quantities and one or two scattered examples. The " most text books " to which Mr. Fairthorne refers are concerned, I suppose, with electrical theory; if this is the case, writers on electrical theory are to be congratulated on retaining a less insular attitude towards other branches of science than is shown by their mechanically-minded colleagues.

It is surprising that the elementary characteristics of mechanical and electrical oscillations should ever have been studied separately; if the properties of the basic differential equations are ascertained, the properties of mechanical or electrical systems are obtained by substituting the appropriate physical quantities for the mathematical coefficients. I have personal knowledge, however, of electrical engineers engaged in mechanical vibration research who have wished to convert the mechanical systems to electric circuits, and have been unable to do so; the process I describe enables the conversion to be made without resort to the differential equations—a simplification which appeals to those who are not primarily mathematicians.

When reference is made to the basic differential equations, and retaining force and e.m.f. as analogous quantities, it is difficult to see the logical basis for identifying inductance and " spring," or capacity and mass. I am indebted to Mr. Fairthorne for bringing this " analogy " to my notice.

Yours,

R. G. MANLEY.

P.S.—In my paper may I make two small corrections? The caption to Fig. 1 on p. 7 should be deleted, and the reference to Fig. 9 on p. 20 should have been deleted from the mss. as I decided a diagram was not necessary.

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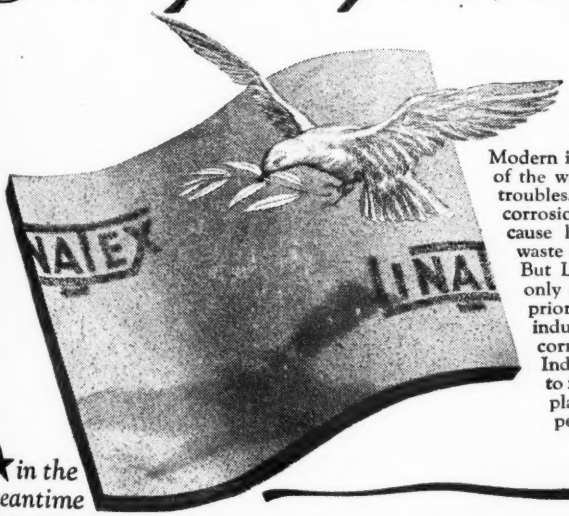

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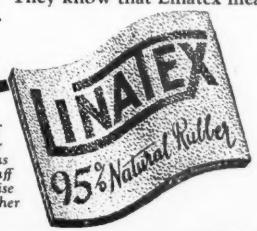

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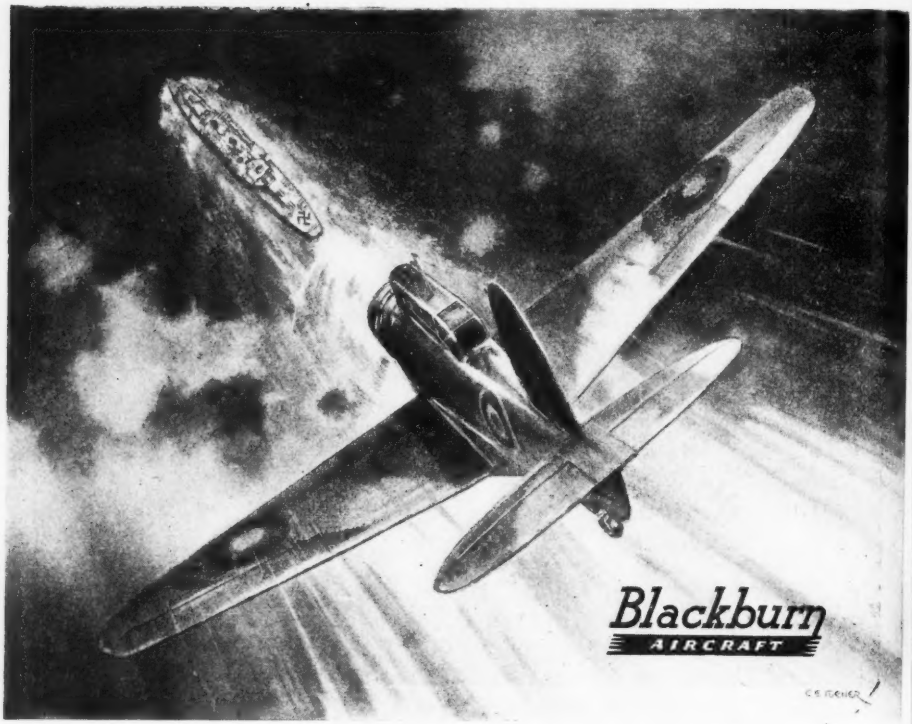

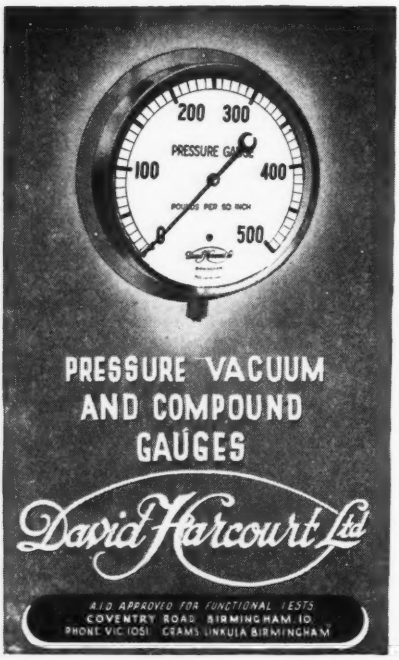

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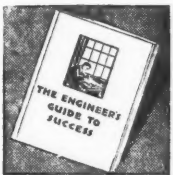

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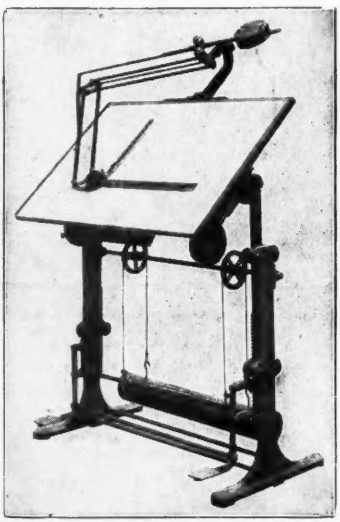

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